US009096454B2

(12) **United States Patent**
Nakao et al.

(10) **Patent No.:** **US 9,096,454 B2**
(45) **Date of Patent:** **Aug. 4, 2015**

(54) **MANUFACTURING METHOD FOR SHEET GLASS AND MANUFACTURING METHOD FOR GLASS SUBSTRATE**

(71) Applicant: **FURUKAWA ELECTRIC CO., LTD.,** Tokyo (JP)

(72) Inventors: **Kousuke Nakao**, Tokyo (JP); **Toshiyuki Asai**, Tokyo (JP)

(73) Assignee: **FURUKAWA ELECTRIC CO., LTD.,** Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/212,433**

(22) Filed: **Mar. 14, 2014**

(65) **Prior Publication Data**

US 2014/0196501 A1   Jul. 17, 2014

Related U.S. Application Data

(63) Continuation of application No. PCT/JP2012/071285, filed on Aug. 23, 2012.

(30) **Foreign Application Priority Data**

Nov. 10, 2011   (JP) 2011-246809

(51) **Int. Cl.**
C03B 23/037	(2006.01)
G01B 5/00	(2006.01)
G01B 21/08	(2006.01)
G01B 5/06	(2006.01)
C03B 21/00	(2006.01)
C03B 21/04	(2006.01)

(52) **U.S. Cl.**
CPC *C03B 23/037* (2013.01); *C03B 21/00*

(2013.01); *C03B 21/04* (2013.01); *G01B 5/00* (2013.01); *G01B 5/06* (2013.01); *G01B 21/08* (2013.01)

(58) **Field of Classification Search**
CPC C03B 23/037; C03B 21/00
USPC 65/29.11, 29.14, 105
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,361,431	A *	11/1982	Kandachi et al.	65/99.5
6,385,998	B1	5/2002	Mizuno	
8,107,856	B2	1/2012	Gotoh et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

EP	2 157 059 A1	2/2010
JP	6-305756 A	11/1994

(Continued)

OTHER PUBLICATIONS

International Search Report issued on Nov. 13, 2012 for PCT/JP2012/071285 filed on Aug. 23, 2012 in English.

(Continued)

Primary Examiner — Queenie Dehghan
(74) *Attorney, Agent, or Firm* — Oblon, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

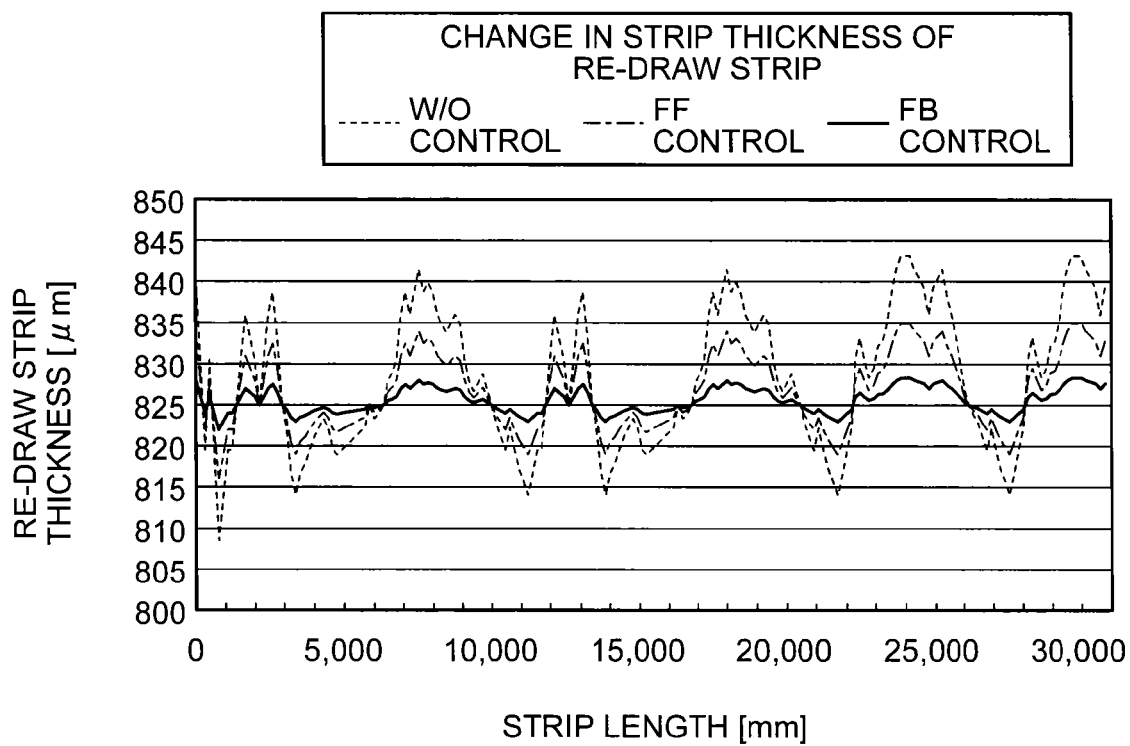A method of manufacturing a sheet glass includes: a re-draw process forming a sheet glass by, heating and softening a glass preform manufactured by float method, and extending the glass preform to a desirable plate thickness. An extension direction in which the glass preform is extended by the re-draw process is 90 degrees with respect to a direction in which molten glass is fed in the float method.

5 Claims, 8 Drawing Sheets

(56)   **References Cited**

U.S. PATENT DOCUMENTS

2006/0021385 A1	2/2006	Cimo et al.	
2009/0113935 A1	5/2009	Suzuki et al.	
2009/0324995 A1*	12/2009	Todo et al.	428/846.9
2010/0242702 A1	9/2010	Tanise et al.	
2011/0014428 A1	1/2011	Nakamura	

FOREIGN PATENT DOCUMENTS

JP	11-199255	A	7/1999
JP	2000-203857	A	7/2000
JP	2001-080929	A	3/2001
JP	2006-244870	A	9/2006
JP	2007-119290	A	5/2007
JP	2008-508179	A	3/2008
JP	2009-244870	A	10/2009
JP	2010-030807	A	2/2010
JP	2011-153059	A	8/2011
WO	2008/136239	A1	11/2008
WO	2009/057474	A1	5/2009
WO	2009/119826	A1	10/2009
WO	2011/132646	A1	10/2011

OTHER PUBLICATIONS

Notice of Reasons for Refusal of Corresponding Japanese Application No. 2011-246809 (Mailed Feb. 12, 2013) with English Translation, 5 pgs.

* cited by examiner

FIG.1

FIG.2

CHANGE IN PLATE THICKNESS
OF PREFORM (A-TYPE)

- A-TYPE LEFT
- A-TYPE RIGHT

PLATE THICKNESS [mm]

PREFORM LONGITUDINAL POSITION [mm]

FIG.3

CHANGE IN PLATE THICKNESS
OF PREFORM (B-TYPE)

- B-TYPE LEFT
- B-TYPE RIGHT

PLATE THICKNESS [mm]

PREFORM LONGITUDINAL POSITION [mm]

FIG.4

FIG.5A

MEASUREMENT POINT	MEASUREMENT POINT	MEASUREMENT POINT

31

31a

31a

FIG.5B

THICK-
NESS
OF PRE-
FORM

D

FIG.5C

THICK-
NESS
OF
STRIP

Δ

FIG.6

FIG.7

FIG.8

CHANGE IN STRIP THICKNESS OF RE-DRAW STRIP

W/O CONTROL · · · · · · · · · ·   FF CONTROL — · — · —   FB CONTROL ——

RE-DRAW STRIP THICKNESS [μm]

850
845
840
835
830
825
820
815
810
805
800

0   5,000   10,000   15,000   20,000   25,000   30,000

STRIP LENGTH [mm]

FIG.9

90

90

64

FIG.10

POSITION IN WIDTH DIRECTION [mm]

FIG.11

POSITION IN WIDTH DIRECTION [mm]

MANUFACTURING METHOD FOR SHEET GLASS AND MANUFACTURING METHOD FOR GLASS SUBSTRATE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of PCT International Application No. PCT/JP2012/071285 filed on Aug. 23, 2012 which claims the benefit of priority from Japanese Patent Application No. 2011-246809 filed on Nov. 10, 2011, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to method for manufacturing a sheet glass formed by heating and extending a glass preform and method for manufacturing a glass substrate using the sheet glass.

2. Description of the Related Art

Conventionally, substrates of semiconductor elements, spacers used for field-effect-type flat panel displays or glass sheets used for magnetic disc substrates etc. require better thickness uniformness or surface roughness.

As a method of manufacturing a sheet glass having prede-termined thickness and improved surface roughness, a method etc. of heating and softening a glass preform and extending it into a desirable thickness of sheet glass has been proposed (see Japanese Laid-open Patent Publication No. H11-199255).

SUMMARY OF THE INVENTION

It is an object of the present invention to at least partially solve the problems in the conventional technology.

In accordance with one aspect of the present invention, there is provided a method of manufacturing a sheet glass, the method includes: a re-draw process forming a sheet glass by, heating and softening a glass preform manufactured by float method, and extending the glass preform to a desirable plate thickness. An extension direction in which the glass preform is extended by the re-draw process is 90 degrees with respect to a direction in which molten glass is fed in the float method.

In accordance with another aspect of the present invention, there is provided a method of manufacturing a glass substrate includes sheet-glass-manufacturing process manufacturing a sheet glass by the method of manufacturing a sheet glass according to the present invention, and coring process coring in one line so that a center of the glass substrate is positioned substantially on a center in a width direction of the sheet glass.

The above and other objects, features, advantages and tech-nical and industrial significance of this invention will be better understood by reading the following detailed descrip-tion of presently preferred embodiments of the invention, when considered in connection with the accompanying draw-ings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic view showing a float plate accord-ing to an embodiment of the present invention and two kinds of glass preforms cut out from the float plate;

FIG. 2 is a graph showing plate thickness profile along the longitudinal direction of an A-type glass preform according to the embodiment of the present invention;

FIG. 3 is a graph showing plate thickness profile along the longitudinal direction of a B-type glass preform as a compari-son example according to the embodiment of the present invention;

FIG. 4 is a schematic view showing a general configuration of a sheet-glass-manufacturing apparatus adopting the re-draw method according to the embodiment of the present invention;

FIG. 5A is a glass preform in which positions is measured in the embodiment of the present invention;

FIG. 5B is a graph of plate thickness profile of the glass preform along the longitudinal direction of the glass preform;

FIG. 5C is a graph of strip thickness profile of a sheet glass correspond to the longitudinal direction of the glass preform;

FIG. 6 is a graph showing pull-in speed control along the length of a preform by a sheet-glass-manufacturing apparatus according to the embodiment of the present invention;

FIG. 7 is a graph showing change in strip thickness of a sheet glass manufactured by a sheet-glass-manufacturing apparatus adopting the re-draw method according to the embodiment of the present invention;

FIG. 8 is a graph showing strip thickness profile along the longitudinal direction of a re-draw strip manufactured based on a control method according to the embodiment of the present invention;

FIG. 9 is a diagrammatic view for explaining a method of coring a glass substrate from a sheet glass manufactured according to the embodiment of the present invention;

FIG. 10 is a graph showing thicknesses along the width direction of a glass substrate manufactured by the method of manufacturing a glass substrate according to the embodiment of the present invention and a glass substrate manufactured by conventional art; and

FIG. 11 is a graph showing thicknesses along the width direction of a glass substrate manufactured by the method of manufacturing a glass substrate according to the embodiment of the present invention and a glass substrate manufactured by conventional art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, an embodiment of the present invention will be explained with reference to the drawings. Furthermore, in all the drawings of the embodiment hereafter, identical or equivalent elements are given same reference numerals. In addition, the present invention is not limited by the embodi-ment explained as follows.

At first, a method of manufacturing a sheet glass according to the embodiment of the present invention will be explained. FIG. 1 is a view schematically showing a glass preform used in the method of manufacturing a sheet glass according to this embodiment and a float plate from which the glass preform is cut out.

As shown in FIG. 1, at first, a float plate 10 manufactured by the float method is prepared. That is, the float plate 10 is formed by filling molten metal tin into a float bath (not shown) and flowing, on its surface, molten glass so as to float thereon. Furthermore, in FIG. 1, a hollow arrow indicates a flow direction of the molten glass as a flow direction of the float. This float method is capable of stable and inexpensive mass-production of large-area sheet glass. Furthermore, metal such as tin etc. as ion intrudes into a surface of one side of the float plate 10, making contact with the metal tin; thus a tin surface 20 is formed. This tin surface 20 may be removed.

Next, a material process is conducted by cutting this float plate 10 into a desirable size of glass preform. Glass preforms

31, 32, and 33 cut out in the material processing of cutting out these glass preforms 31 to 33 and 41 so that their longitudinal directions are disposed at 90 degrees with respect to the flow direction of the float are called "A-type glass preforms". On the other hand, the glass preform 41 cut out in the material processing so that its longitudinal direction is in parallel with the flow direction of the float is called "B-type glass preform". Furthermore, regarding dimension of these glass preforms 31 to 33 and 41, length L_0 is 2000 mm, width W_0 is 600 mm, and thickness t_0 is, 3 mm, for example.

FIG. 2 shows the result of measuring the thickness of the A-type glass preform 31 in its longitudinal direction, at two end portions in its width direction, that is, lateral end portions (arrow portions of the solid line and the dotted line in FIG. 1) respectively relative to the longitudinal direction. FIG. 3 shows the result of measuring thickness of the B-type glass preform 41 in its longitudinal direction, at lateral end portions relative to the longitudinal direction respectively. Furthermore, the dotted-line arrow shown in FIG. 1 indicates a left end portion relative to the longitudinal direction, and the solid-line arrow indicates a right end portion relative to the longitudinal direction.

It is understood from FIG. 2 that the plate thickness profile of the A-type glass preform 31 varies along the longitudinal direction at both of the left end portion and the right end portion relative to the longitudinal direction, i.e., increases from 3.16 mm to 3.22 mm at maximum and decreases from this maximum value to 3.14 mm. That is, the plate thickness profile of the A-type glass preform 31 is found to be in a mountain-shape in its longitudinal direction.

In contrast, it is understood from FIG. 3 that, the plate thickness profile of the B-type glass preform 41 is approximately constant at about 3.135 mm along the longitudinal direction at the left end portion relative to the longitudinal direction and remains approximately constant at 3.165 mm along the longitudinal direction at the right end portion relative to the longitudinal direction. That is, it is understood that the plate thickness of the B-type glass preform 41 is approximately constant along the longitudinal direction of the glass preform 41 at the left end portion and the right end portion respectively.

In addition, it is understood from FIG. 2 that difference of the thicknesses of the A-type glass preform 31 at the left end portion and at the right end portion relative to its longitudinal direction is very small. On the other hand, it is understood from FIG. 3 that difference of the thicknesses of the B-type glass preform 41 at the left end portion and at the right end portion relative to its longitudinal direction is greater than those of the A-type glass preform 31.

The reason for the thickness profile thus formed is considered as follows. That is, when forming the float plate 10 by the float method, molten glass when being fed onto metal tin exhibits behavior as fluid. Therefore, change in the thickness along the feed direction of the molten glass, i.e., the feed direction of the float is small, and on the other hand, change in the thickness along a direction perpendicular to the feed direction of the float is great. For this reason, in the whole float plate 10, the thickness tends to be approximately constant when being along the feed direction of the float, and on the other hand, the thickness tends to vary to a great degree when being along the direction perpendicular to the feed direction of the float. That is, difference of the plate thicknesses of the A-type glass preform 31 is great when being along the longitudinal direction, but is small when being along the width direction. On the other hand, difference of the plate thick-

nesses of the B-type glass preform 41 is small when being along the longitudinal direction, but is great when being along the width direction.

Based on the above described study, and since other glass preforms 32 and 33 are supposed to be cut out from the float plate 10 in this order along the feed direction of the float as shown in FIG. 1, the inventor of the present invention further imagined that the glass preforms 32 and 33 would resemble the glass preform 31 in shape. That is, the other A-type glass preforms 32 and 33 also have greater change in the plate thickness profiles and in the thickness difference along their longitudinal directions, and on the other hand, the other A-type glass preforms 32 and 33 also have smaller change in the plate thickness profiles and in the thickness difference along their width directions. In addition, tendency of the plate thickness profile of the glass preform 32 cut out from the adjacent glass preform 31 resembles tendency of the plate thickness profile of the glass preform 31, and tendency of the plate thickness profile of the glass preform 33 resembles tendency of the plate thickness profile of the glass preform 32. As described above, the A-type glass preforms 31, 32, and 33 being adjacent to each other and cut out from the same float plate 10 are supposed to coincide with each other approximately in their shapes or plate thickness profiles.

Incidentally, when manufacturing a sheet glass by the re-draw method of which detail will be explained later, a glass preform is supposed to be extended in the longitudinal direction. In this manufacturing, ordinarily, strip thickness distribution of a sheet glass herein manufactured reflects the plate thickness profile of a glass preform in the width direction to a great degree, and on the other hand, the strip thickness distribution of the sheet glass herein manufactured is capable of alleviating the influence of the plate thickness profile in the longitudinal direction. Therefore, in this embodiment, the A-type glass preforms 31, 32, and 33 are used to produce a sheet glass because the plate thickness in the width direction is approximately constant and changes small.

Next, a sheet-glass-manufacturing apparatus according to the embodiment of the present invention and a method of manufacturing a sheet glass by using this sheet-glass-manufacturing apparatus will be explained. FIG. 4 is a schematic view of a sheet-glass-manufacturing apparatus adopting the re-draw method according to this embodiment.

As shown in FIG. 4, the sheet-glass-manufacturing apparatus 50 adopting the re-draw method has an upper holder unit 51, a center holder unit 54, a connection heater unit 55, a lower holder unit 57, a heating furnace 59, a pull-in capstan 60, and a cutter 63. Furthermore, the sheet-glass-manufacturing apparatus 50 is provided with driver units C1, C2, C3, C4, and C5 driving the upper holder unit 51, the center holder unit 54, the connection heater unit 55, the lower holder unit 57, and the pull-in capstan 60 respectively. In addition, the sheet-glass-manufacturing apparatus 50 is provided with a control unit 65 controlling these units, the driver units C1 to C5 driving these units, the heating furnace 59, and the cutter 63. Furthermore, the sheet-glass-manufacturing apparatus 50 is provided with a plate thickness measurement unit 52 and a strip thickness measurement unit 56 as various kinds of measurement means. The plate thickness measurement unit 52 is disposed beneath the upper holder unit 51 or above the center holder unit 54, and is a preform-thickness measurement unit measuring the thicknesses of the glass preforms 31 to 33. In addition, the strip thickness measurement unit 56 is disposed beneath the pull-in capstan 60 and is a strip thickness measurement apparatus measuring the thickness of the formed re-draw strip 61. Furthermore, values measured by these plate

thickness measurement unit **52** and the strip thickness measurement unit **56** respectively are supplied to the control unit **65** as data.

In the sheet-glass-manufacturing apparatus **50**, the upper holder unit **51** has two pairs of holder units **51a** and **51b** holding a rear end (upper end) of the glass preform **33**. These holder units **51a** and **51b** are configured to be rotatable by the driver unit C**1** controlled by the control unit **65** by a predetermined angle around an axis (Z direction) in the longitudinal direction of the glass preform **33**. In addition, the upper holder unit **51** compensates for the position of the glass preform **33** in the thickness direction (X direction) or the width direction (Y direction) by the driver unit C**1**. Furthermore, when compensating for position, the driver unit C**1** causes the upper holder unit **51** to move in the thickness direction (X direction) or to rotate the glass preforms **31** to **33**. In addition, the plate thickness measurement unit **52** provided above the center holder unit **54** measures the plate thickness of the glass preform **33**, which is being moved, along its longitudinal direction.

The center holder unit **54** has two pairs of holder units **54a** and **54b** holding the left end portion and the right end portion in the width direction of the rear end of the glass preform **32**. These holder units **54a** and **54b** are configured to be movable in the vertical direction (Z direction) by the driver unit C**2** controlled by the control unit **65**. The glass preform **32** compensated for its position by the upper holder unit **51** is held by these holder units **54a** and **54b**, thus, it is possible to move the glass preform **33** in the feed direction (–Z direction).

The connection heater unit **55** moves in synchronization with the movement, in a feed direction, of a connecting portion of the preceding glass preform **31** and the glass preform **32** subsequently fed after the glass preform **31**. This movement is performed by the driver unit C**3** controlled by the control unit **65**. The connection heater unit **55** includes a pair of connection heaters **55a** and **55b** arranged symmetrically so that the connection heaters **55a** and **55b** place connecting portions of the glass preforms **32** and **33** in the vicinity of connecting portions of the glass preform **31** and the glass preform **32** in the thickness direction. This symmetric arrangement of the pair of the connection heaters **55a** and **55b** makes a profile of increase in temperature in the thickness direction of the glass preforms **31** and **32** symmetric or makes glass viscosity profile symmetric, thus warpage caused by asymmetry in the thickness direction can be restrained.

The lower holder unit **57** has two pairs of holder units **57a** and **57b** holding a rear end portion of the glass preform **31** actually supplied to the heating furnace **59**. The respective holder units **57a** and **57b** pinch and hold the glass preform **31** at the left end portion and the right end portion of the glass preform **31** in the thickness direction. The lower holder unit **57** is moved and controlled so as to be capable of feeding the glass preforms **31** to **33** sequentially into the heating furnace **59** by the driver unit C**4** controlled by the control unit **65**. In addition, heaters (not shown) are provided at portions respectively where the two pairs of the holder units **57a** and **57b**, when holding the glass preform **31**, make contact with the glass preform **31**. These heaters are temperature-controlled by the control unit **65** so as to reach to temperature close to that of the glass preform **31** being held.

The control unit **65** controls and drives the driver units C**2** and C**4** for these center holder unit **54** and the lower holder unit **57** respectively, thus the speed at which the glass preform is fed into the heating furnace **59** is controlled. Furthermore, the rear end of the preceding glass preform **31** and the front end of the succeeding glass preform **32** are butt-joined. The portions connected by butt-joint are welded by the connection

heater unit **55**, and also the speed in case of feeding the glass preforms **31** and **32** into the heating furnace **59** continuously is controlled by the control unit **65**.

The heating furnace **59**, into which the glass preform **31** is fed, is an electric resistance furnace configured to be capable of heating the glass preform **31** from its two sides. Provided inside the heating furnace **59** is a heater (not shown) as a heating apparatus heating the glass preform **31**.

The pull-in capstan **60** provided at a pulling side of the heating furnace **59** has two pairs of rollers **60a** and **60b** pulling, and while extending, the glass preform **31**. The respective rollers **60a** and **60b** are configured to be capable of being rotated and driven by the driver unit C**5** controlled by the control unit **65**. In addition, since the control unit **65** controls the rotation speed of the respective rollers **60a** and **60b**, pull-in speed at which the glass preform **31** is pulled while being extended is controlled. In addition, the strip thickness measurement unit **56** disposed at a down-stream side with respect to the glass preform **31** being pulled and beneath the pull-in capstan **60** measures the strip thickness of a re-draw strip **61** obtained after the glass preform **31** was extended. The strip thickness herein measured corresponds to the plate thickness of the sheet glass **64** which will be explained later.

After the glass preform **31** is extended by the pull-in capstan **60** and formed to a re-draw strip **61**, this re-draw strip **61** is cut by the cutter **63** by a predetermined length L (mm), thus a sheet glass **64** is manufactured. Furthermore, regarding dimension of the sheet glass **64** manufactured in this embodiment, length L is 300 mm, width W is 110 mm, and thickness t is 0.825 mm, for example.

Furthermore, although the re-draw strip **61** is cut by the cutter **63** to manufacture the sheet glass **64** in this embodiment, in case where the re-draw strip is sufficiently flexible, the re-draw strip may be wound, in state of not being cut, around a reel to produce the sheet glass **64**.

Next, a control method when manufacturing the sheet glass **64** by using the sheet-glass-manufacturing apparatus **50** configured as above according to this embodiment will be explained.

At first, a method of controlling feed speed for the glass preforms **31** to **33** by the center holder unit **54** and the lower holder unit **57** and pull-in speed for the glass preforms **31** to **33** by the pull-in capstan **60** by feed-forward control is explained. FIG. **5** is a graph showing measurement position for the plate thickness of the glass preform, a graph of plate thickness profile along the longitudinal direction of the glass preform, and the strip thickness profile of the re-draw strip **61** corresponding to the glass preform. Furthermore, a connection loss portion **31a**, used when being connected to another glass preform, exists at two end portions (front-and-rear ends) in the longitudinal direction of the glass preform **31** as shown in FIG. **5A**.

In addition, of the glass preform **31**, difference of thicknesses in plate thickness profile along the width direction is small, and on the other hand, plate thickness difference D of the plate thickness profile along the longitudinal direction is great. When the inventors measured, the plate thickness difference D of the glass preform **31** used in this embodiment was approximately 250 μm. Furthermore the plate thickness difference D is not necessarily limited to this value.

In addition, since the glass preform **31** is extended by the pull-in capstan **60** to be formed to the re-draw strip **61**, the strip thickness profile along the longitudinal direction of the re-draw strip **61** usually reflects the plate thickness profile along the longitudinal direction of the glass preform **31**. Based on that, this embodiment reduces strip thickness dif-

ference of strip thickness profile along the longitudinal direction of the re-draw strip **61** by controlling at least one of feed speed and pull-in speed for the glass preforms **31** to **33** by the control unit **65**.

That is, at first, as shown in FIG. **5A**, the plate thickness profile of the glass preform **31** is measured along the longitudinal direction by the plate thickness measurement unit **52**. Hereby data for the plate thickness profile along the longitudinal direction of the glass preform **31** can be obtained. Furthermore, as described above, the plate thickness profiles of the A-type glass preforms **31** being cut out adjacently coincide with each other approximately. Therefore, after the plate thickness profile is measured temporarily, thickness is measured at least at three points by the plate thickness measurement unit **52** based on this plate thickness profile, and then the measured value of the plate thickness is shifted, thereby the plate thickness profile of the glass preform **31** can be derived. FIG. **5B** shows data for obtained plate thickness profile of the glass preform **31**. Data of the plate thickness profile of this glass preform **31** are supplied from the plate thickness measurement unit **52** to the control unit **65**.

Next, the control unit **65** performs feed-forward control on the feed speed V and the pull-in speed v for the glass preform **31** based on data, of the plate thickness profile of the glass preform **31**, supplied from the plate thickness measurement unit **52** so that variation in the strip thickness of the re-draw strip **61** is reduced. This control is executed by relating the feed speed V and the pull-in speed v for the glass preform **31** based on desirable strip thickness of the re-draw strip **61** (target strip thickness) and the plate thickness profile of the glass preform **31**.

More specifically, the relationship between the feed speed V (mm/min) of plate thickness T (mm) of the glass preform and the pull-in speed v (m/min) in case that the re-draw strip **61** is of strip thickness t (mm) can be described by Numerical Formula (1) as follows. This Numerical Formula (1) is preferably applicable to a case where an aspect ratio (ratio of plate thickness and width) of a cross section perpendicular to the longitudinal direction of the glass preform is equal to an aspect ratio (ratio of strip thickness and strip width) of a cross section perpendicular to the longitudinal direction of the re-draw strip **61**.

[Numerical Formula 1]

$$v = \frac{1}{1000}\left(\frac{T}{t}\right)^2 V \qquad (1)$$

Furthermore, when manufacturing the sheet glass **64**, since the target strip thickness of the re-draw strip **61** is constant (t: constant), relationship between the feed speed V and the pull-in speed v of the glass preform **31** is described also by Numerical Formula (2) as follows.

[Numerical Formula 2]

$$\frac{v}{V} \propto T^2 \qquad (2)$$

As shown in Numerical Formula (2), the ratio of the pull-in speed v to the feed speed V of the glass preform **31** is in proportion to the square of the plate thickness of the glass preform **31**.

Thereby the control unit **65** in this embodiment performs feed-forward control, based on the plate thickness profiles of the glass preforms **31** to **33** and in response to the fluctuation of its plate thickness T, so that at least one of the feed speed V and the pull-in speed v of the glass preform **31** satisfies Numerical Formula (1). That is, both the feed speed V of the glass preform **31** and the pull-in speed v of the re-draw strip **61** may be controlled variably, otherwise, one of the speeds may be controlled to be fixed and constant and the other one of the speeds may be controlled variably.

Herein, in this embodiment, in order to restrain generation of waviness of the glass substrate as a final product by reducing twist in the glass preform **31** inside etc. the heating furnace **59**, it is preferable that the control unit **65** controls so that, while the feed speed V of the glass preform **31** is constant, the pull-in speed v is variably controlled. In case of controlling the pull-in speed v variably in this manner, feed-forward control is executed as follows. That is, in case of extending a relatively thick portion of the plate thickness profile of the glass preform **31**, the pull-in speed v of the pull-in capstan **60** is increased so as to be able to pull up quickly, so that the strip thickness of the formed re-draw strip **61** is reduced to approximate to the target value. In contrast, in case of extending a relatively thin portion of the plate thickness profile of the glass preform **31**, the pull-in speed v is decreased so as to pull up slowly and to a small degree, so that the strip thickness of the formed re-draw strip **61** is increased to approximate to the target value. In addition, the pull-in speed v is changed in this manner at a predetermined interval of feed, more specifically, for example, 50 mm, of the glass preform **31**.

FIG. **6** is a graph showing a specific example of transition of pull-in speed v changed and controlled in this manner. Furthermore FIG. **6** shows the pull-in speed v which corresponds to the position from the front end of the glass preform **31** along the longitudinal direction. As shown in FIG. **5B** and FIG. **6**, in a portion where the glass preform **31** is thin and the plate thickness is small along the longitudinal direction of the glass preform **31**, the control unit **65** controls so that the pull-in speed v by the pull-in capstan **60** is slow. Hereby the strip thickness t of the formed re-draw strip **61** increases and the plate thickness of the manufactured sheet glass **64** approximates the target value. On the other hand, in a portion where the glass preform **31** is thick and the plate thickness is great, the control unit **65** controls so that the pull-in speed v by the pull-in capstan **60** increases. Hereby the strip thickness t of the formed re-draw strip **61** decreases and the plate thickness of the manufactured sheet glass **64** approximates the target value.

As described above, by controlling the pull-in speed v corresponding to the plate thickness profile of the glass preform **31**, it is possible to restrain the plate thickness profile of the glass preform **31** from being reflected on the strip thickness profile of the formed re-draw strip **61** directly, and thus, the difference of strip thicknesses in the strip thickness profile of the re-draw strip **61** can be narrowed. Furthermore, in case of forming the re-draw strip **61** by using a glass preform **31** similar to the glass preform **31** used in the embodiment and by maintaining the feed speed V and the pull-in speed v of the glass preform **31** constantly, as shown in FIG. **5C**, the strip thickness difference Δ along the longitudinal direction of the re-draw strip **61** formed by a portion which is other than the connection loss portion **31**a of the glass preform **31** was 30 to 40 μm at maximum. In contrast to this, in this embodiment, it was confirmed that, by controlling the pull-in speed v by the control unit **65** based on the plate thickness profile, along the longitudinal direction of the glass preform **31**, measured pre-

viously by the plate thickness measurement unit **52**, as shown in FIG. **5**C, the strip thickness difference Δ of the re-draw strip **61** formed by the portion which is other than the connection loss portion **31**a of the glass preform **31** is equal to or smaller than 20 µm.

Next, a control method of executing feed-back control focusing on the pull-in speed v for further reducing non-uniformness in the strip thickness t of the re-draw strip **61** will be explained. FIG. **7** is a graph, for explaining feed-back control by this embodiment, showing measured values and average values of the strip thickness t of the re-draw strip **61** at positions along the longitudinal direction of the glass preform **31**.

At first, as shown in FIG. **7**, change in the strip thickness of the re-draw strip **61** formed by using a piece of glass preform **31** is measured (dotted line in FIG. **7**). Next, based on the measured change in the strip thickness of the re-draw strip **61**, the control unit **65** calculates average values of the strip thickness of the re-draw strip **61** at a predetermined interval at which the glass preform **31** is fed along the longitudinal direction, for example, 50 mm (solid line in FIG. **7**). Next, the control unit **65** calculates difference between the calculated average value of the strip thickness t of the re-draw strip **61** and the target strip thickness of the re-draw strip **61**. In FIG. **7**, in case that the target strip thickness of the re-draw strip **61** was 825 µm for example, the control unit **65** calculates difference between the average value (solid line in FIG. **7**) of the strip thickness of the re-draw strip **61** and 825 µm.

Subsequently, the control unit **65** calculates a value for compensating for the pull-in speed v, by the pull-in capstan **60** when forming the re-draw strip **61**, based on the difference between this calculated average value of the strip thickness and the target strip thickness. Furthermore this value for compensating for the pull-in speed v is calculated at an interval of calculating the above-described average value of the strip thickness t of the re-draw strip **61**, i.e., every time the glass preform **31** is fed by 50 mm, for example.

More specifically, in case that the calculated average value of the strip thickness of the re-draw strip **61** is greater than the target strip thickness, the control unit **65** calculates and sets, based on the difference, the value for compensation to be greater than the pull-in speed v when forming the re-draw strip **61** from the glass preform **31**. In contrast, in case that the calculated average value of the strip thickness of the re-draw strip **61** is smaller than the target strip thickness, the control unit **65** calculates and sets, based on the difference, the value for compensation to be smaller than the pull-in speed v when forming the re-draw strip **61** from the glass preform **31**.

In addition, these values compensating for the pull-in speed v is calculated over the entire length of the glass preform **31** when using the glass preform **31** to form the re-draw strip **61**. After that, change in the pull-in speed v at which the re-draw strip **61** was formed from the glass preform **31** is fed back, thus change in new pull-in speed v, to which the values for compensation were applied, is set. Then, this change in the pull-in speed v is applied to pull-in speed v when forming the re-draw strip **61** from the glass preform **32** fed subsequent to the preceding glass preform **31**.

As described above, since the glass preforms **31** to **33**, which are adjacent to each other, are cut out from a same float plate **10** continuously, the plate thickness profile of the preceding glass preform **31** and the plate thickness profile of the succeeding glass preform **32** have the same tendencies substantially. Therefore, the pull-in speed v of the glass preform **32** can be optimized by applying and feeding back the values, compensating for the pull-in speed v, calculated based on the strip thickness profile of the re-draw strip **61** formed from the

preceding glass preform **31** to the pull-in speed v of the subsequent glass preform **32**. Hereby the strip thickness of the re-draw strip **61** can approximate to the target strip thickness. As described above, since the A-type glass preforms **31** to **33** are adopted, feed-back control of the pull-in speed v can be executed more effectively by supplying the glass preforms **31** to **33** to the sheet-glass-manufacturing apparatus **50** sequentially in the order of being disposed adjacently in the float plate **10**.

FIG. **8** shows the strip thickness profiles of the manufactured re-draw strip in the longitudinal direction in case of executing the above-described feed-forward control (FF control), in case of executing the feed-back control (FB control), and in case of maintaining the feed speed of the glass preform and the pull-in speed of the glass preform constantly.

As shown in FIG. **8**, in case of not executing feed-forward control and feed-back control, there is a part (dotted line part in FIG. **8**) in which shift amount from the target value is equal to or greater than 15 µm. In contrast to this, equal to or smaller than 10 µm of shift amount was possible by executing the feed-forward control (dash dotted lines in FIG. **8**), and it was possible to reduce the shift amount to equal to or smaller than 5 µm by further executing the feed-back control (solid line parts in FIG. **8**).

Next, a glass substrate formed from the sheet glass manufactured by the sheet-glass-manufacturing apparatus **50** as described above will be explained.

At first, a flat and disc-shaped glass substrate **90** shown in FIG. **9** is casted from a sheet glass **64** manufactured in the above-described manner by executing a known coring process. In the coring process, the flat and disc-shaped glass substrates **90** are cut out sequentially in one line from the manufactured sheet glass **64** so that the center of the glass substrate **90** is positioned on the center in the width direction of the sheet glass **64** substantially.

Furthermore the flat and disc-shaped glass substrate **90** not having a hole at the center portion was used here; a doughnut-shaped glass substrate having a round hole at the center portion may be used. FIG. **10** and FIG. **11** show results of measuring plate thickness profiles which are equivalent to the width direction of the sheet glasses **64** of two arbitrarily-selected glass substrates **90** in case that one of the glass substrates **90** was manufactured by using the A-type glass preform **31** and the other one of the glass substrates **90** was manufactured by using the B-type glass preform **41**. Furthermore, in any case, a sheet glass was used which was manufactured by maintaining the feed speed and the pull-in speed of the glass preform constantly without executing the feed-forward control and the feed-back control. Since the above-described feed-forward control or feed-back control improves the plate thickness profile by reducing the plate thickness difference along the direction in which the sheet glass **64** is extended and thus do not affect the plate thickness difference along the width direction, similar results can be obtained even in case of executing feed-forward control or feed-back control.

It is understood from FIG. **10** that the plate thickness difference of the glass substrate **90** manufactured from the B-type glass preform **41** is approximately 8 µm, and in contrast to this, the plate thickness difference at two sides of the glass substrate **90** manufactured from the A-type glass preform **31** adopted in this embodiment has improved to approximately 3 µm. In addition, it is understood from FIG. **11** that the plate thickness difference of the glass substrate **90** manufactured from the B-type glass preform **41** is approximately 8 µm, and in contrast to this, the plate thickness difference at two sides of the glass substrate **90** manufactured from the

A-type glass preform **31** has improved to approximately 4.5 μm. That is, it was confirmed that variation of the plate thickness of the glass substrate **90** can be reduced to a great degree and uniformness of the plate thickness improves by manufacturing the glass substrate **90** by using the sheet glass **64** manufactured from the A-type glass preforms **31** to **33** by the re-draw method. Furthermore, the glass substrate **90** as a product is manufactured by executing known edge-forming process, end-surface-polishing process, and primary-surface-grinding process to the glass substrate **90** casted in the above-described manner.

According to the above described embodiment of the present invention, it is possible to reduce variation in the plate thickness along the width direction of a sheet glass manufactured from a glass preform so that this glass preform used for manufacturing the sheet glass is the glass preform cut out so that the longitudinal direction is in 90 degrees with respect to the feed direction of the molten glass when manufacturing the float plate to maintain the plate thickness along the width direction of the glass preform constantly. In addition, since it is possible to prevent the plate thickness profile varying to a relatively greater degree along the longitudinal direction of the glass preform from being reflected on the strip thickness profile of the re-draw strip directly by controlling the feed speed or the pull-in speed of the glass preform based on this plate thickness profile; thus a desirable plate thickness of the sheet glass excellent in the uniformness of the plate thickness can be manufactured; therefore, variation in the plate thickness of the glass substrate as a final product can be reduced to a great degree and the uniformness of the plate thickness of the glass substrate can be improved furthermore.

As described above, although the embodiment of the present invention was explained specifically, this invention is not limited to the above-described embodiment, and various modifications are possible based on a technical idea of this invention. For example, values described in the above-described embodiment are mere examples, and values different from these may be used if necessary.

Although, in the above-described embodiment, the plate thickness measurement unit **52** provided to the sheet-glass-manufacturing apparatus **50** is configured to measure the plate thicknesses of the glass preforms **31** to **33** to supply these measured values to the control unit **65**, a plate thickness measurement device disposed outside the sheet-glass-manufacturing apparatus **50** may be configured to measure the plate thicknesses of the glass preforms **31** to **33** in advance to supply the measured values to the control unit **65**.

In addition, the above-described embodiment is configured to control the pull-in speed of the glass preform **31** by using Numerical Formula (1) according to the plate thickness of the glass preform **31** but not limited to Numerical Formula (1) necessarily, and it is possible to use various numerical formulae according to the plate thickness of the glass preform **31** if it is possible to control the feed speed V and the pull-in speed v of the glass preform **31** at the optimum speed mutually according to the dimension of the glass preform **31** or the desirable dimension etc. of the sheet glass **64**.

In addition, although, in the above-described embodiment, the control unit **65** executes feed-back control of the pull-in speed v automatically, this feed-back control can be executed manually. That is, it is possible to execute feed-back control in which, one to three pieces of glass preform is used to form re-draw strips, values compensating for the pull-in speed v are calculated at a predetermined length of feeding the glass preform, e.g. every time the glass preform is fed by 50 mm, based the difference between the strip thickness profiles of these re-draw strips and the target strip thickness of the re-

draw strip, and then, based on these values for compensation, the pull-in speed v when forming the re-draw strip **61** from subsequently-fed glass preform **32** is compensated for manually.

In addition, although, in the above-described embodiment, the plate thickness of the glass preform **31** is measured by the plate thickness measurement unit **52** at three points along the longitudinal direction when executing feed-forward control based on the plate thickness profile of the glass preform **31**, this measurement of the plate thickness by the plate thickness measurement unit **52** can be executed over the entire length along the longitudinal direction of the glass preform **31**.

In addition, although, in the above-described embodiment, it is configured that the pull-in speed v of the glass preform **31** is switched and changed every time the glass preform **31** is fed by 50 mm, the pull-in speed v of the glass preform **31** may be changed successively according to the plate thickness profile of the glass preform **31**.

In addition, in the above-described embodiment, it is possible to manufacture the sheet glass by maintaining both the feed speed of the glass preform and the pull-in speed of the glass preform constantly without executing neither one of the feed-forward control and the feed-back control.

The present invention can be used preferably when manufacturing a sheet glass or a glass substrate used for, for example, solar cell modules, semiconductor element substrates, spacers used for field-effect-type flat panel displays, or magnetic disc substrates etc.

Although the invention has been described with respect to specific embodiments for a complete and clear disclosure, the appended claims are not to be thus limited but are to be construed as embodying all modifications and alternative constructions that may occur to one skilled in the art that fairly fall within the basic teaching herein set forth.

What is claimed is:

1. A method of manufacturing a sheet glass, the method comprising a re-draw process forming a sheet glass by, heating and softening a glass preform manufactured by float method, and extending the glass preform to a desirable plate thickness, wherein

    an extension direction in which the glass preform is extended by the re-draw process is 90 degrees with respect to a direction in which molten glass is fed in the float method.

2. The method according to claim **1**, further comprising a control process controlling at least one of feed speed of the glass preform and pull-in speed at which the glass preform is pulled based on plate thickness profile of the glass preform.

3. The method according to claim **1**, further comprising a pull-in-speed control process controlling, based on plate thickness profile of the glass preform, pull-in speed at which the glass preform is pulled, wherein

    the pull-in-speed control process comprises a pull-in speed compensation process which comprises

measuring plate thickness profile along the extension direction of the sheet glass formed by a preceding first glass preform, calculating a compensation value compensating for the pull-in speed, at which the first glass preform is pulled, based on profile of difference between the measured plate thickness profile of the sheet glass and a target plate thickness of the sheet glass, and compensating for pull-in speed of a second succeeding glass preform by using the compensation value.

4. The method according to claim **3**, wherein the first glass preform and the second glass preform are cut out from positions adjacent in a direction in which molten glass is fed in the float method.

5. A method of manufacturing a glass substrate, the method comprising:

a sheet-glass-manufacturing process of manufacturing a sheet glass by performing a re-draw process of forming the sheet glass by, heating and softening a glass preform manufactured by a float method, and extending the glass preform to a desirable plate thickness, wherein an extension direction in which the glass preform is extended by the re-draw process is 90 degrees with respect to a direction in which molten glass is fed in the float method; and

a coring process of coring the sheet glass to form glass substrates in one line so that centers of the glass substrates are positioned substantially on a center of the sheet glass in a width direction.

* * * * *